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How Much Biodiversity for the Future: Our Choice, Our Responsibility

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The papers in this symposium volume illustrate many effective approaches to carrying out an inventory of the world's organisms. Some advocate a survey as complete as possible, others a sampling approach. All would like to see as extensive a series of studies on the biodiversity of the Earth as we can manage. Some groups of organisms, such as nematodes, fungi, and mites, are so poorly known that it does not seem possible to inventory them completely within any reasonable period of time. For the prokaryotes, bacteria, and Archaea, completing an inventory is so difficult that no clear picture of their diversity has emerged yet, despite their enormous importance for us.

Because it is so daunting to attain a comprehensive picture of Earth's biodiversity in an age of extinction, I consider that it would be best to develop relatively complete inventories of those groups that are relatively well known, such as vertebrate animals, plants, butterflies, and a few others. For more incompletely known groups of organisms, it seems to me that it would be more constructive to devise rational methods of sampling than to continue our present approaches as if a complete inventory will be possible. With appropriate sampling, we could estimate the dimensions of global diversity and outline biogeographical patterns. At the same time, it seems important to study the whole constellation of organisms that occur in particular places that are important because of the broad ecological and other studies that are conducted there. Such places certainly include La Selva in Costa Rica, Barro Colorado Island in Panama, and Hubbard Brook in Connecticut — places where it would be of great interest to understand the interactions of all kinds of organisms. In general, Long Term Ecological Research (LTER) sites, established by the National Science Foundation in the 1980s and emulated throughout the world, in many cases have been surveyed for biodiversity and would serve such purposes well if studied over the years in even more depth. This is basically the strategy laid out by Raven (1980).

Extinctions Past and Present: How Many Species are We Talking About

Our current level of knowledge of eukaryotic organisms on Earth is very poor, with some 1.6 million named of a total that very probably exceeds 10 million; only a few thousand of these are known to a reasonable degree of detail (May 2000). For prokaryotes, as mentioned, we have no real idea of how many there may be, and any estimates are premature (Dykhuizen 1998; Curtis, et al. 2002). There are relatively few systematic biologists fully employed in developing an inventory of any group of organisms, and far more species exist than they could possibly catalog within a reasonable period of time. Despite our collective lack of knowledge, we expect to be able to utilize organisms, many of them unknown at present, in a variety of ways that would contribute to the sustainable production of food, medicine, shelter, and clothing — and yet we have not even recorded the existence of at least five-sixths of them, and perhaps an even higher proportion!

We also would like to understand the ways in which organisms occur together in communities and ecosystems, and to enhance the ecosystem services that they provide in such abundance and without any direct cost to us. In an age of molecular biology, comparative genomics, and the possibility of gene transfer between distantly related species, our global stock of organisms has taken on a new meaning in relation to our efforts for building sustainability for the future. If the present century is to be "the age of biology," we need as many kinds of organisms as we can save to build that age. We enjoy and appreciate organisms, and wonder about their effects on the nature of our origins, our language, our psychologies, our brains. Obviously, we are completely connected with them in an extraordinary range of ways.

We also worry very much about the rate at which our population growth, increasing levels of consumption, and use of inappropriate or unsustainable technologies are driving them to extinction. Some 65 million years ago a giant asteroid collided with the Earth at a position that is now off the end of the Yucután Peninsula in Mexico, throwing up a long-lasting, dark cloud of debris that ultimately brought about the extinction of an estimated two-thirds of all terrestrial species (Pimm and Brooks 2000). Following millions of years of recovery from that catastrophe, the number of eukaryotic organisms began to climb towards the estimated 10 million species that exist now.

Over the long period of time that followed the asteroid collision, some 65 million years, we judge rates of extinction from the fossil record of groups of organisms that have hard body parts, and which are, therefore, well preserved in the fossil record. From such examination, it can be estimated that the average life of a species has been several million years (Pimm 2001). On average, about one species per million has gone extinct per year. Over the long period since the last major extinction, 65 million years, those species that have disappeared have been more than replaced by newly-evolved ones as the total number has climbed toward its present level. The pace of extinction has, however, increased markedly during the past few centuries, as I shall discuss in more detail. General reviews of the topics treated in the next few paragraphs have been provided by Pimm (2001) and Raven (2001, 2002), among many others.

Following the development of crop agriculture some 10,500 years ago in the eastern Mediterranean region, a rapid human population explosion took hold. Villages grew into towns and ultimately cities, while the fabric of civilization became increasingly complex. Within the past 2000 years, the number of people on Earth reached several hundred million, then 1 billion for the first time in the first half of the 19th century, 2 billion in 1930, 2.5 billion in 1950, and 6.3 billion in 2003, according to figures supplied by the Population Reference Bureau. These increases in population were accompanied by increases in the level of consumption per person, and those increases have been very unequally distributed as societies have become stratified. More recently the stratification has been intensified with the development of political units, which in our day are basically nations.

As we enter the 21st century, about 20 percent of the people on Earth, those who live in industrialized countries, control about 80 percent of the world's wealth. In general, they consume at a level 30 to 40 times that of rural people in developing countries. Overall, our collective level of consumption has been estimated by Mathis Wackernagel to amount to 120 percent of what the planet can produce sustainably, having increased sharply from 70 percent in 1970, and still continuing its precipitous climb upward (Wackernagel, et al. 2002). All over the world, people are planning to consume even more in the future, as many developing world economies, notably those of China and India, grow very rapidly.

Although some of us live very rich lives, with levels of consumption that would have been unimaginable just a few decades ago, most human beings live lives of abject poverty — half of all the world's people subsist on less than $2 per day, and a quarter of us on less than $1 per day. Approximately half of the people on Earth are malnourished in respect to some essential dietary requirement, and a sixth of our total population consists of people who are literally starving — surviving on less than 80 percent of the U.N.-recommended minimum caloric input per day, so that their bodies are literally wasting away and their brains fail to develop properly when they are children. As we have seen, the human population is already consuming the world's resources at 120 percent of the rate at which they are being replaced. Our total population, by moderate estimates, is projected to grow by an additional 2 billion people before it starts to stabilize around the middle of this century. In the face of these numbers, it does not appear structurally possible to improve the lot of most people without seriously rethinking what each of us needs, how it is going to be obtained, and how we can improve our relationships with and understanding of one another.

To mention a few specific environmental effects, the combination of population growth, affluence (consumption), and non-sustainable technology is having a very obvious negative effect on the global environment. Since 1950, an estimated 20 percent of the topsoil, 20 percent of the agricultural land, and a third of the world's forests has been lost, while the CO_2 in the atmosphere has increased by about a sixth and the stratospheric ozone layer has been depleted 6 to 7 percent. In the early 21st century, we are estimated to be using, wasting, or diverting at least 45 percent of the world's terrestrial photosynthetic productivity and 55 percent of the world's sustainable supplies of fresh water (Vitousek, et al. 1986; review in Pimm 2001). No wonder that the rate of extinction of biodiversity is increasing rapidly!

How can we determine this rate if we have named only about a sixth of the estimated number of species of eukaryotic organisms? It can be approximated by referring to what is recorded about the members of well-known groups — largely vertebrate animals and vascular plants, together with a few others such as butterflies, some groups of beetles and mollusks, and so forth. Using the estimate presented earlier of one species per million per year over the past 65 million years as a baseline, we can examine subfossil records and publications over the past 300 or so years, since the time when people began to describe the living world adequately, and by doing so estimate what the extinction rate has been during this period (Pimm and Brooks 2000). For the relatively well-known groups of organisms just enumerated, we can estimate that the extinction rate has climbed to hundreds, and now thousands, of species per year. Where is it going?

In making this determination, it is important to examine the effects of the four prime causes driving the process of species extinction in the 21st century. The first and most obvious of these is habitat destruction. The relationships demonstrated in the field of island biogeography have shown that the relationship between species number and area either for islands or on the mainland in a more or less uniform habitat is a logarithmic one. Thus the reduction of an area to one-tenth of its original size will lead to the extinction of approximately half of the species that occurred there originally. The tropical moist forests remaining by mid-century are projected to constitute about 5 percent of their original area, and inasmuch as these forests are estimated to be home for about half of the species on Earth (perhaps five million species or more), such a reduction could in itself lead to the loss of about a third of the estimated number of eukaryotic species (Pimm and Brooks 2000). In a major chapter of recent extinction, the loss of habitat as the Polynesians colonized the islands of the Pacific over the past 1500 years and cleared their lowlands and valleys for agriculture, combined with their hunting activities, is estimated to have led to the loss of as many as 1000 species of birds there, of a world total of some 9000 species, over this short period of time (Pimm 2001).

Hunting and gathering wild species of plants and animals are another important cause of extinction focused on a particular species. For example, hunting bush meat, an activity that is particularly important in Africa, coupled with increasing numbers of people, is seriously damaging prospects for survival of many species of vertebrates; and yet it is the most relatively available source of protein in many areas. The taste for bush meat as a delicacy in affluent extra-tropical centers such as London is also a driving force for its illegal export, as is the expectation that lumbering and other working crews in the field in Africa will provision themselves.

Gathering plants in nature can be equally damaging, especially in view of the enormous quantities of herbal remedies and dietary supplements that are being exported to Japan, Europe, and the United States. For most of the people of China and India, which have a combined population of about 2.4 billion people (of a world total of 6.3 billion), plants are their medicine. Only about 15 percent of the needs are met from cultivated sources, however, and the impact on native plants that are used in this way can easily be imagined. Middlemen generally buy their supplies from those who scour the countryside to gather them, making substantial profits in the process.

A third very important driving force for extinction is the growing worldwide spread of aggressive, invasive alien species of plants, animals, fungi, and microorganisms. Thus, about a third of the species of plants in the northern hemisphere are estimated to be endangered or threatened with extinction because of competition with introduced weeds. In Hawaii, about half the native species of plants are threatened or endangered, almost all as a result of the activities of introduced plants or animals. The introduction of avian malaria into the Hawaiian Islands together with the mosquitoes that spread it (there were no mosquitoes in the Islands originally) has been a very serious contributor to the endangerment and extinction of native land birds (review in Pimm 2001). In other parts of the world, various species of *Phytophthora*, an oomycete, have been introduced and wrecked great havoc. In many cases involving fungi and microorganisms, it is difficult to determine what the original ranges may have been because our overall knowledge of the groups is so poor. At any rate, one species of *Phytophthora* is endangering native scrub over wide areas of Australia, particularly in the southwestern part of the continent. Half the world away, sudden oak death, caused by another species of the genus, is killing large numbers of native oaks and other woody plants in California. Alien species continue to spread rapidly, and clearly will exert an even greater negative influence on natural communities in the years to come.

Recently, it has become evident that global warming will make the survival of many species problematic, even in the absence of other factors, and that the influence of global warming on natural populations will increase greatly in the near future. The mean global temperature is estimated to have increased 0.8° Celsius since 1750, the baseline, and most of this increase has taken place in recent decades. As the emission of CO_2 and other gases continues and increases as currently projected, global temperatures are expected to increase by an additional 3°C or more by 2050, and would in principle continue to rise indefinitely if we do not take steps to curtail them, according to analyses presented by the International Panel on Climate Change. Future temperatures will vary locally, so that mean temperatures in continental areas such as the upper Great Plains and Midwestern area of the United States are predicted to increase two to three times the average. The effects of increases in average temperatures on the distribution and amount of precipitation are unpredictable, but clear; as such further changes occur, the damage to biodiversity caused directly by the increased temperatures will be magnified. Regardless of what happens to local precipitation, increased temperatures alone will render many conserved areas unsuitable habitats for the organisms and communities for which they were established. Excellent analyses of the predicted fates of individual species have been prepared for South Africa and Australia, but we are just beginning to consider such effects, with much more information to be available in the near future (Thomas et al. 2004). Certainly it appears likely that habitats of many species will simply disappear as the climate shifts. For the lower 48 states of the United States, it is predicted that global warming will eliminate all habitats above timber line by the end of the century; similarly drastic changes are likely to occur in other biological communities unless energy policies are altered significantly in all nations.

On the basis of habitat destruction alone, it has been estimated that two-thirds of the species of terrestrial eukaryotic organisms on Earth could become extinct by the end of the present century (Pimm and Brooks 2000). Such a rate of extinction would be equivalent to that which happened at the end of the Cretaceous Period, some 65 million years ago, but the extinction that our children and grandchildren are likely to witness will have been caused by the activities of one species acting alone — the direct effect of human activities. Because this estimate is based on habitat loss alone, the other factors just enumerated can only make it much more severe. Of these factors, global warming is perhaps the least predictable and at the same time potentially the most damaging factor. It is important that additional analyses be performed so that we can deal with the consequences of global warming on biodiversity much better than we do at present, and then act on our findings. Another consideration of general importance is that biodiversity certainly cannot be preserved well in parks and reserves alone. We must learn to promote and understand concepts such as "countryside ecology," proposed by Gretchen Daily and her colleagues, and "reconciliation ecology," proposed by Michael Rosezweig, and to care for biodiversity effectively in the full range of habitats in which it exists.

At any event, all these negative trends taken together lend an urgency to charting and saving biological diversity that could not have been imagined just a few decades ago. Many papers in this symposium reflect ways in which this effort can be expedited and the quality of our collective effort improved. It is, however, also important that we biodiversity specialists, being well informed both about this situation and its consequences, help to provide adequate information both to our fellow citizens and to those who make political decisions that affect the future of biodiversity.

It follows from the considerations just presented that the preservation of biodiversity depends on conserving it to the extent possible wherever it exists, including urban areas. In addition, the traditional goal of preserving parks and other natural areas as repositories of biodiversity remains an extremely important strategy in any overall plan that might be conceived. The United States has been a global leader in this effort, and has done a great deal to help other nations establish equivalent protected areas for their own biodiversity. The passage of the Endangered Species Act in 1972 has provided a cornerstone of our subsequent activity in preserving biological diversity, and for plants especially cultivation in gardens and preservation in seed banks, followed in principle by re-introduction in nature, has been an important supplementary conservation activity.

In dealing with invasive species, many strategies must be employed in controlling them where they have been introduced and in preventing further introductions to the extent possible. This will involve increased inspection activities at national and other borders as well as the cooperation of industries such as marine and other shipping, the nursery and landscaping industries, and many others.

Prospects for Preserving Biodiversity

For the preservation of biodiversity overall, however, it will be necessary greatly to improve international understanding and cooperative international activities. As mentioned above, we are using the sustainable productivity of the world at 120 percent of the level at which our current rate of consumption can be sustained. To achieve sustainability for our planet as a whole, and thus protect the unique planetary resource on which we depend, it will be essential for those of us who live in the industrialized countries to form close bonds with all others and help everyone to move to sustainability together. Our realization that sustainability is a global problem, however, is only about 30 years old, and the degree to which we are willing to act on the situation remains problematical. As long as we live in a world that is deeply divided between the haves and the have-nots, with wealth and scientific expertise highly concentrated in a few countries, we have no chance of attaining global sustainability.

We who are scientists and engineers know well that expertise in our fields makes it possible for a nation to adopt the findings of others in the same areas, which mean so much to economic progress in our time. In addition, such expertise allows individual nations to use their own national resources in the best possible and sustainable ways, based on their own experience and knowledge. Unfortunately, there are more than 150 countries that have only a few such specialists, and these nations constitute about 40 percent of the world's population, mostly in areas of high biological diversity. More than 10 percent of the world's scientists and engineers practice their professions in India, Brazil, China, and Mexico, which collectively have about 40 percent of the world's population, and almost all of the remaining 90 percent live in industrialized countries, which collectively are home to less than 20 percent of the world's people (Population Reference Bureau statistics). It is no surprise that these industrialized countries also control such a substantial majority of the world's wealth, and cause a nearly equivalent proportion of the world's pollution, directly or indirectly. Ultimately, the preservation of biodiversity depends on understanding and managing the world sustainably. Conservation cannot be achieved by itself, because there cannot then be enough room, time, or resources to save so many species.

As biologists, we need to be a very concrete part of the overall solution, an obligation that our knowledge places on us. Certainly, collaborative research projects, participating in the training of scientists and engineers from developing countries, and working to insure that they have positions in which they can use their knowledge for the improvement of human knowledge and the benefit of their own countries are important. But we can also be internationalists and inform all groups of whom we are members of the importance of all countries around the world to us. With some 4.5 percent of the world's people, the United States consumes 25 percent of the world's resources and produces about an equivalent amount of pollution, which is enough to link us firmly with all other countries on Earth, regardless of how we decide to deal with that relationship.

In the 1960s, René Dubois devised the maxim, "Think globally, act locally." No matter what our profession, we can contribute greatly to the attainment of sustainability worldwide by paying attention to and caring for the environment around us — the parks and green spaces, recycling efforts, conservative use of energy, including renewable sources of energy, and many other aspects of sustainability that affect us personally and our daily lives. People in developing countries do not, by and large, have nearly as much impact on the environment as each and every one of us who live in industrialized countries, and we must look to our own individual demands and style of living if we wish to move toward the implementation of global sustainability. If nearly every one of us wishes to, and plans to, consume more resources than we do at present, and would like to have a better house, more money to send our children to universities, a better car, nicer vacations, and so forth, it is not realistic to expect governments or corporations to assume a "no growth" policy, or work towards the creation of a sustainable world in a less materialistic way. To arrive at that point, we need to consider why we in the United States use twice as much energy per capita as any other country on Earth, and why the standard of living in countries such as Switzerland, Sweden, or Germany is then approximately the same as ours. The only viable reason to be an optimist in the modern world is because of our individual determination to do something about the great problems that face us, and the privileges that we enjoy demand that we do nothing less. Participation in the political process is extremely important, because there is often no other way to achieve solid results in these areas.

The world is apparently not coming to an end, but it may offer people very different opportunities in 2050 or 2100 than it does now, its nature depending very much on the actions we take now, during the period when explosive growth in population and consumption levels has brought what may be the most destructive phase in the history of mankind on this Earth. The opportunities available to us now are, by definition, greater than they ever will be in the future, and we must take advantage of them while this is still possible. My overall point is that anyone who cares about the future of biodiversity in the world must also care about, and work for, the establishment of a sustainable world.

Biodiversity is extremely important to our future and that of our fellow citizens, regardless of how they may view it individually. Our food, much of our medicine, our building materials, and, in the early years of understanding molecular biology, our understanding of how genes function and our sources of new genes — these all depend on biodiversity. Understanding it, enjoying it, conserving it, and appreciating it as the single unique factor that makes life possible on Earth. No one could possibly predict where our understanding of biology will take us in the future, but no one can doubt that conserving as much as possible of the biodiversity as we possess now is a highly desirable strategy regardless of what our motivation may be. And that is why it is important for us to become active not only in the study of biodiversity, but also in its preservation through the contributions we can make to a sustainable planet.

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